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NATURAL REGENERATION AFTER SHELTERWOOD CUTTING IN A GRAND FIR-SHASTA RED FIR STAND IN CENTRAL OREGON

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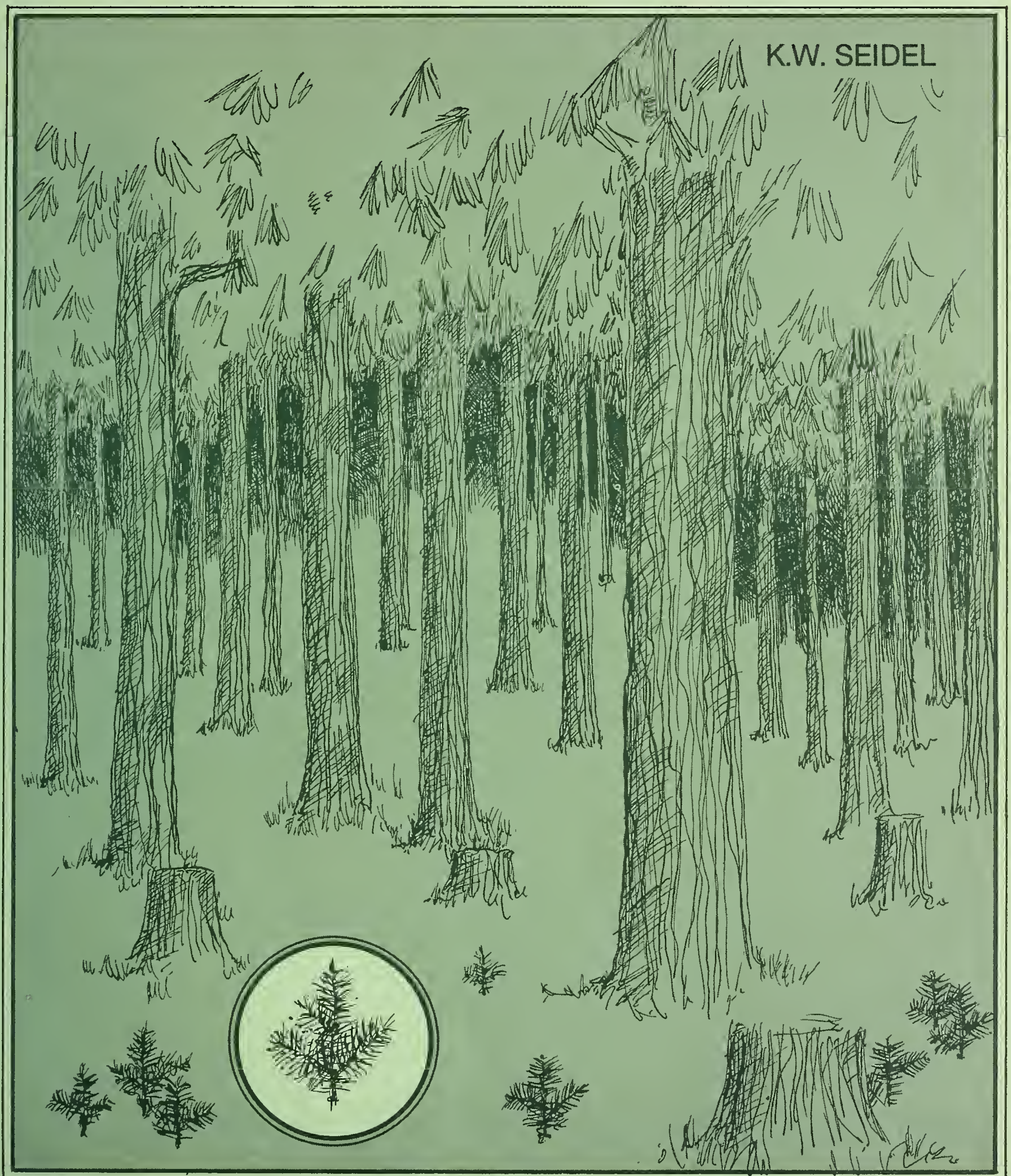

Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service

Metric Equivalents

1 acre = 0.405 hectare
1 foot = 0.304 8 meter
1 inch = 2.54 centimeters
1 mile = 1.61 kilometers
1 square foot = 0.0929 square meter
1 square foot/acre = 0.229 6 square meter/hectare
1 tree/acre = 2.47 trees/hectare

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NATURAL REGENERATION AFTER SHELTERWOOD CUTTING IN A GRAND FIR-SHASTA RED FIR STAND IN CENTRAL OREGON

Reference Abstract

Seidel, K. W.
1979. Natural regeneration after shelterwood cutting in a grand fir-Shasta red fir stand in central Oregon. USDA For. Serv. Res. Pap. PNW-259, 23 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Natural regeneration was good to excellent 5 years after shelterwood cutting to three overstory densities (50, 90, and 130 ft^2 per acre) in a mixed conifer stand on the Deschutes National Forest in central Oregon. Seedling density ranged from about 1,875 per acre on the low density plots to 4,627 per acre on the high density plots and consisted of about 85 percent true fir (grand and Shasta red) and 15 percent ponderosa, lodgepole, and western white pine. Mineral soil was the most favorable seed bed for germination and seedling survival, but many true fir seedlings did become established in light to medium litter layers. A residual overstory of about 50 ft^2 of basal area per acre appears adequate to provide natural regeneration within a 5-year period.

KEYWORDS: Shelterwood cutting method, regeneration (natural), grand fir, *Abies grandis*, Shasta red fir, *Abies magnifica* var. *shastensis*, Oregon (central).

Research Summary
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1979

In 1973, a study was begun on the Deschutes National Forest to obtain information about natural regeneration using the shelterwood system in an old-growth mixed conifer stand. The aim was to determine the effects of several residual overstory density levels and several slash treatments on establishment and growth of the regeneration. Changes in seedling numbers and stocking, seed production, seed bed condition, and understory vegetation for a 5-year period after the seed cut were evaluated.

The study stand was located in a mixed conifer/manzanita plant community and averaged about 74 trees per acre of which 85 percent were true fir (grand and Shasta red) and the remainder pine (ponderosa, lodgepole, and western white pine). Average diameter was about 20 inches for grand fir, 28 inches for red fir and 30 inches for ponderosa pine.

Residual overstory densities tested on whole plots were 50, 90, and 130 ft^2 of basal area per acre or an average of 16, 31, and 58 trees per acre. Slash treatments tested on the split-plots were none, lop and scatter, remove all litter and slash with bulldozer, and crush slash with bulldozer.

Two heavy true fir cone crops and three light to medium crops were produced during the 5-year period. The heavy cone crops occurred at the beginning and end of the study period. Seed trap catches showed a total of 108,000 sound seed per acre fell on the low density plots during the study period as compared with 125,000 on the medium density plots and 259,000 on the high density plots.

Natural regeneration 5 years after the seed cut ranged from about 1,875 seedlings per acre on the low density plots to 4,627 per acre on the high density plots, and distribution over the plots was excellent; stocked milacres ranged from 65 to 74 percent. As expected, subplots where nearly all the mineral soil was exposed proved to be the most receptive to seedling establishment at all three overstory density levels. Little difference in seedling numbers was found between the other slash treatments. Although mineral soil was the most favorable seed bed for germination and seedling survival, many true fir seedlings did become established in light to medium (up to 1/2 inch in depth) litter layers. Complete litter and slash removal is neither necessary nor desirable. In general, species composition of the natural regeneration was similar to that of the mature stand before logging.

Soil moisture was readily available to seedlings during the growing season, and seedling moisture stress never reached critical values. The principle cause of seedling mortality during the summer appeared to be high surface temperatures since temperatures of 163° F (72.8° C) were reached even on the high overstory density plots.

Understory vegetation was sparse in the study area before logging. It did not increase significantly during the 5-year study period and was not a problem in seedling establishment.

In this mixed conifer/manzanita plant community, it appears that a residual overstory basal area of about 50 ft^2 per acre after the seed cut is sufficient to provide adequate natural regeneration within a 5-year period. Skillful application of logging and slash disposal techniques are essential to preserve the established reproduction when the residual overstory is removed.

CONTENTS

INTRODUCTION

The upper slope mixed conifer forests of the Oregon Cascade Range can be managed with a number of silvicultural systems--both even- and uneven-aged. In the 1950's and early 1960's, primarily clearcutting was used to harvest true fir stands on National Forest lands. Success of natural regeneration on these clearcuts has been mixed; in some cases true fir stocking has been adequate (Gratkowski 1958), but in others natural reproduction has been lacking (Franklin 1965).

Recognizing that some type of partial cutting might moderate the microclimatic extremes occurring in clearcuts and thus provide a more favorable environment for seedling establishment, the Forest Service began using the shelterwood system in the 1960's as an alternative to clearcutting in the upper slope types.

Although the shelterwood system is now used extensively in east-side Oregon and Washington mixed conifer forests, information is lacking regarding the relationship of seedling establishment to residual stand density, or the effect of various seed beds on seedling survival. Therefore, in 1973, I began a study to obtain some insights into the natural regeneration response of a true fir stand in the eastern Cascades of central Oregon. This paper reports detailed information on seed production, seedling establishment and growth, seed bed conditions, and understory vegetation response for a 5-year period after the seed cut in a two-stage shelterwood system.

OBJECTIVES

The primary objective of this study was to determine the effect of several intensities of shelterwood cuttings and several types of slash treatments in a mature true fir stand on the establishment, survival, and height growth of the natural regeneration. A secondary objective was to determine soil and seedling moisture stress and surface temperature conditions existing during the first growing season and to observe understory vegetation response.

STUDY AREA

The study site is located in a single 50-acre old-growth mixed conifer stand on Royce Mountain on the Crescent Ranger District of the Deschutes National Forest about 10 miles northwest of Cresent, Oregon on a south-facing 10-percent slope at an elevation of about 5,600 feet.[1] The soil is a well drained Regosol (Vitrandept) developed in dacite pumice ejected from Mount Mazama (Crater Lake) about 6,500 years ago. It has an A1, AC, C1, C2 pumic horizon about 3 to 4 feet deep over the buried soil which is a sandy loam Paleosol developed in older volcanic ash.

Before study installation, basal area ranged from 150 to 300 ft^2 per

[1] Metric equivalents are on inside front cover.

acre and most trees were over 150 years old. Gross volume (Scribner) averaged about 36,000 board feet per acre. There were about 74 trees per acre, of which 75 percent were grand fir (*Abies grandis* (Dougl.) Lindl.),[2/] 11 percent Shasta red fir (*A. magnifica* var. *shastensis* Lemm.), 8 percent ponderosa pine (*Pinus ponderosa* Laws), and 2 percent each of lodgepole pine (*Pinus contorta* Dougl.), western white pine (*Pinus monticola* Dougl. ex D. Don), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Average diameter was about 20 inches for grand fir, 28 inches for red fir, and 30 inches for ponderosa pine. Site index of grand fir based on Schumacher's (1926) curves indicates a height of 53 feet at age 50.

The study area is located in a mixed conifer/manzanita plant community (Volland 1976). Ground vegetation consists primarily of pinemat manzanita (*Arctostaphylos nevadensis*), kinnikinnick (*A. uva-ursi*), and prince's pine (*Chimaphilla umbellata*). Small amounts of other genera such as *Stipa, Carex,* and *Epilobium* are also present. The litter and duff layer of the forest floor before logging generally was present throughout the study area in a compact mat about 1 to 2 inches deep with less than 5 percent mineral soil exposed.

[2/] Grand fir and white fir (*Abies concolor* (Gord. & Glend.) Lindl.) form a continuously varying biological complex in eastern Oregon. This complex is referred to as grand fir in this paper.

METHODS

The study consists of a completely randomized split-plot design replicated two times for a total of six 1-acre whole plots. Each whole plot was divided into four 1/4-acre subplots. Residual overstory density levels were tested on the whole plots and slash treatments were tested on the subplots. The overstory density factor consists of three levels and was based on leaving 25, 45, and 65 percent of the average basal area of all plots before cutting. This resulted in residual densities of 50, 90, and 130 ft^2 of basal area per acre or an average of 16, 31, and 58 trees per acre (fig. 1). The slash factor consists of four treatments: none, lop and scatter, expose mineral soil by removing all litter and slash with bulldozer, and crush slash by running bulldozer over subplot.

Each 1 acre, whole plot was surrounded by an isolation strip 200 feet in width to minimize seedfall from adjacent plots. Overstory density in the isolation strip was marked to the same basal area level as the plot itself. Leave trees (fully crowned dominants and codominants) were marked on all plots and isolation strips. After logging was completed in the fall of 1973, the four slash treatments were applied to subplots. Varying amounts of advance reproduction were present when plots were established, but nearly all of it was destroyed in the logging and slash disposal operations. In the summer of 1974, a grid of 25 permanent circular 1-milacre plots was

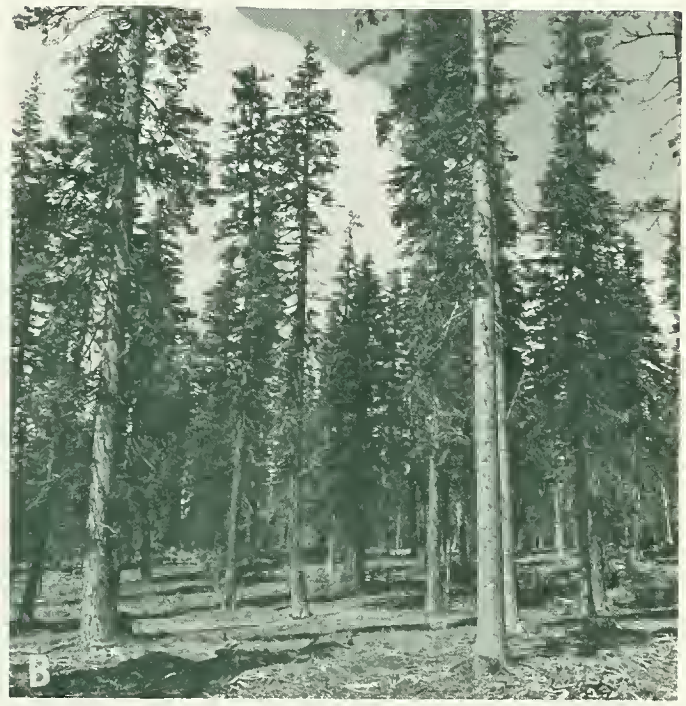

Figure 1.--General view of shelterwood plots after logging in 1973: (A) 50-ft^2 density, (B) 90-ft^2 density, (C) 130-ft^2 density. Species composition of the overstory after the seed cut averaged about 83 percent grand fir and 17 percent red fir on the low and medium density plots. On the high density plots, 90 percent of the trees were grand fir, 3 percent red fir, 4 percent ponderosa pine, 2 percent white pine and, 1 percent lodgepole pine.

established on each 1/4-acre subplot. Milacre plots were systematically spaced at 20-foot intervals on five parallel lines 20 feet apart containing five milacres each. Annually for 5 years beginning in the fall of 1974, the total number of seedlings of each species was counted and recorded on each milacre. Seedlings were identified by year of establishment by placing a color coded wire pin by each seedling so that annual mortality of each years seedlings could be determined. Total height of the tallest seedling of each species was also measured annually on each milacre. The following environmental factors associated with each milacre were measured or observed and recorded at the time of seedling counts: aspect, slope, seed bed condition (mineral soil, litter, slash), and understory vegetation (forbs, shrubs, grass).

Seed bed classes as proposed by Gordon (1970) were used. They are:

Mineral soil: Bare soil or soil with very minor amounts of organic material on the surface or in mixture.

Litter:

Light: Uniform distribution of needles or small twigs over entire surface but mineral soil visible, or small patches of medium litter with mineral soil visible between patches.

Medium: Uniform distribution of needles or small twigs to about 1/4-inch depth, or small patches of heavy litter with mineral soil visible between patches.

Heavy: Needles and small twigs usually 1/4 to 3/4 inch deep but also deeper, generally in a compact mat, little or no mineral soil visible.

Slash:

Light: Small pieces of slash covering less than 30 percent of surface.

Medium: Any size slash covering 30 to 60 percent of surface.

Heavy: Any size slash covering over 60 percent of surface.

Mineral soil was an exclusive surface type; litter and slash were not exclusive. In other words, if a quadrat was classified as mineral soil, no litter and slash combinations were allowed. Thus a given quadrat could receive a classification such as mineral soil, or medium litter, or light litter and heavy slash.

The understory vegetation classes used were:

Light: covering 5-30 percent of milacre.

Medium: covering 30-60 percent of milacre.

Heavy: covering more than 60 percent of milacre.

Seedfall on each whole plot was sampled annually with twenty 2.83-ft^2 traps located on a grid consisting of 5 rows; 4 traps to a row. Seeds were collected annually in June and were cut to determine numbers of sound and empty seed by species.

Overstory basal area density at each milacre was measured with a 10-factor prism in 1974.

Cones on 15 grand fir and 15 red fir trees within the study area were counted annually from 1974 through 1978. Cones were counted with binoculars from the same point each year and only "seen" cones were reported; no factor was used to adjust for "unseen cones."

During the summer of 1975, when numerous newly germinated seedlings were present on the study area, soil moisture content was measured gravimetrically at depths of 3, 6, 12, and 18 inches in two of the slash treatments (bulldozed and none) at each of the three density levels. Soil moisture tension (soil matric potential) was estimated from the soil moisture depletion curve for each depth. Moisture stress (xylem pressure potential) of true fir seedlings was measured periodically during their first growing season with a portable pressure bomb as described by Waring and Cleary (1967). All measurements were taken from 1100 to 1300 hours P.S.T. on seedlings in full sunlight to determine peak stresses.

Surface temperatures of soil and litter were measured in the same subplots used for soil moisture measurements with Tempils[3/] having melting points of 125°, 138°, 150°, and 163° F (51.7°, 58.9°, 65.6°, and 72.8° C).

Analyses of variance were used to test significance of treatment effects.

RESULTS AND DISCUSSION

Seed Production and Dispersal

True fir cone production showed the typical pattern of a year of heavy cone yields followed by several years of light production found by Franklin et al. (1974). Heavy cone crops of both grand fir and Shasta red fir were produced in 1974 and 1978 with light to medium crops during the other years (fig. 2). In 1974, grand fir produced almost twice as many cones per tree, on the average, than red fir; but during the other years red fir cone yield was greater than grand fir.

[3/]Tempils are small, aspirin-sized tablets, with various melting points. Manufactured by Tempil Corporation, 132 W. 22nd S., New York, N.Y. Trade name of product is mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

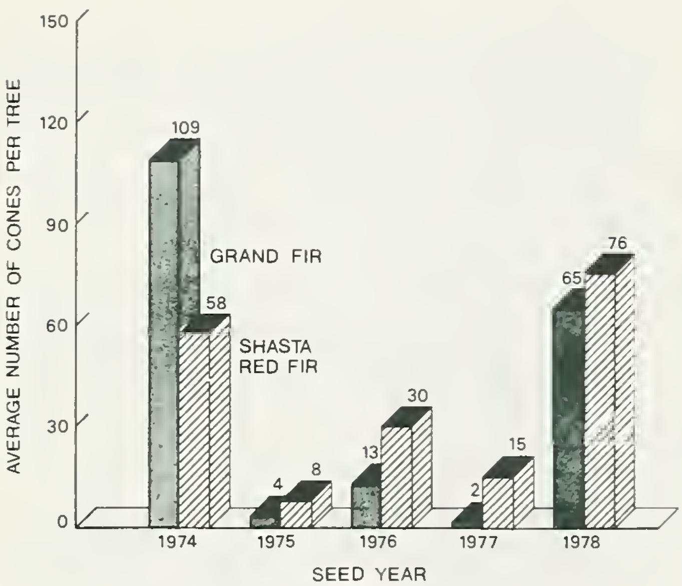

Figure 2.--Average number of cones per tree by species and year. Based on binocular counts of visible cones only. No blow-up factor used to adjust for unseen cones.

As a result of the heavy cone production in the fall of 1974, sound seed falling on the plots during that year was estimated to range from 70,783 per acre on the low density plots (50-ft^2) to 220,474 per acre on the high density plots (130-ft^2) (table 1). This was 23 to 28 percent of the total seed catch for that year. Grand fir seed was the major species found in the traps; comprising about 60 to 80 percent of the total seedfall. Ponderosa and lodgepole pine seed were the smallest component of the total seedfall, but because of their greater soundness sometimes accounted for the bulk of the sound seed on the plots. For example, in 1976, on the high density plots, only 18 percent of the total seed were pine but 79 percent of the sound seed were pine because of the large difference in soundness (54 percent for pine vs. 3.2 percent for fir) (table 1).

The pattern of cone and seed production found in this study together with the cyclical pattern of heavy cone crops at 3- to 4-year intervals reported by Franklin et al. (1974) suggests that there is a good chance of a heavy true fir cone crop occurring at least once in any 5-year period. Obviously a "bumper" crop cannot be expected the first year after the seed cut. In this study no seed was produced in 1973 immediately after logging and seed bed treatments. As long as the seed bed is not occupied at once by aggressive competing vegetation, however, a delay of several years in obtaining a heavy cone crop is not serious.

Seedling Establishment, Survival, and Height Growth

In the fall of 1975, an abundance of 1-year-old seedlings was found on all plots as a result of the heavy cone crop in 1974. On the low (50 ft^2) and medium (90 ft^2) density plots there were about 3,000 seedlings per acre and on the high density (130 ft^2) plots over 7,000 seedlings per acre (fig. 3A and appendix table 9). Seedlings were well distributed over the plots with stocking of the milacre quadrats ranging from 69 to

Table 1--Average number of sound and total seed per acre, with standard errors, falling on plots during the period 1974-1978 by species and density level

Density level and species	Seed Year[1/] 1974 Sound	1974 Total	1974 Percent sound	1975 Sound	1975 Total	1975 Percent sound	1976 Sound	1976 Total	1976 Percent sound	1977 Sound	1977 Total	1977 Percent sound
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50 ft^2												
Grand fir	60,718± 6,600	262,397±13,120	23.1	810± 583	17,823±3,386	4.5	3,240±1,175	62,379±6,858	5.2	9,316±2,056	27,948±5,684	33.3
Shasta red fir	4,233± 1,395	32,200± 4,830	13.1	0 --	3,504±1,296	0	2,025± 689	13,772±2,892	14.7	4,861±1,434	12,152±2,912	40.0
Ponderosa and Lodgepole pine	5,832± 1,632	8,162± 1,795	71.5	385± 385	5,509±1,542	7.0	13,367±2,807	20,658±3,511	64.7	3,240±1,184	5,265±1,454	61.5
Total	70,783± 6,370	302,759±15,138	23.4	1,195± 823	26,836±5,367	4.5	18,632±3,913	96,809±8,713	19.2	17,417±3,603	45,365±8,259	38.4
90 ft^2												
Grand fir	79,270± 7,134	362,872±16,329	21.8	1,540± 976	30,400±5,472	5.1	7,697±1,847	65,033±6,742	11.8	10,176±2,256	33,563±4,862	30.3
Shasta red fir	7,696± 1,847	51,564± 5,672	14.9	0 --	1,539± 875	0	1,540± 862	10,006±2,853	15.4	3,977±1,609	12,528±2,587	31.7
Ponderosa and lodgepole pine	3,463± 1,281	6,542± 1,766	52.9	770± 623	6,927±1,662	11.1	8,081±2,020	19,626±3,612	41.2	428± 428	2,864± 981	14.9
Total	90,429± 8,138	420,978±18,944	21.5	2,310± 785	38,866±4,275	5.9	17,318±3,403	94,665±8,614	18.3	14,581±3,098	48,955±6,167	29.8
130 ft^2												
Grand fir	211,785±10,589	736,640±29,465	28.8	1,154± 750	24,912±5,481	4.6	2,886± 972	93,989±8,512	3.1	14,526±2,727	39,154±4,182	37.1
Shasta red fir	5,550± 1,554	30,927± 4,639	17.9	0 --	385± 385	0	335±335	7,600±1,582	4.4	4,906±1,346	7,119±1,673	68.9
Ponderosa and lodgepole pine	3,139± 1,161	7,028± 1,968	44.7	1,924±1,058	11,281±2,482	17.1	11,833±2,840	21,934±3,412	53.9	865±596	1,250±818	69.2
Total	220,474±11,023	774,595±30,983	28.5	3,078±1,170	36,578±4,755	8.4	15,054±3,312	123,523±9,882	12.2	20,297±3,529	47,523±5,398	42.7

[1/] No seeds were found in any traps from the 1973 seed year.

86 percent[4]. About 70 percent of the regeneration was grand fir, 27 percent Shasta red fir and the rest a mixture of ponderosa pine, lodgepole pine, and white pine.

Removing all litter and slash from subplots by bulldozing exposed mineral soil and provided the most receptive seed bed for seedling establishment. In 1975, seedling numbers on the lop and scatter, crush, and no treatment plots were similar, ranging from 3,300 to 4,000 per acre while the bulldozed plots averaged about 6,500 seedlings per acre (fig. 3B).

Analysis of the 1975 and 1978 seedling density and stocking data showed, as expected, a highly significant difference between the bulldozed treatment and the other three slash treatments for grand fir, red fir, or all species combined. Seedling establishment (all species) was also significantly greater on the high density plots than on the low or medium levels, and there was no significant interaction between overstory density levels and slash treatments. In other words, the effect of the slash treatments on seedling establishment was similar at all overstory density levels; the bulldozing treatment always resulted in considerably greater numbers of seedlings than the other treatments.

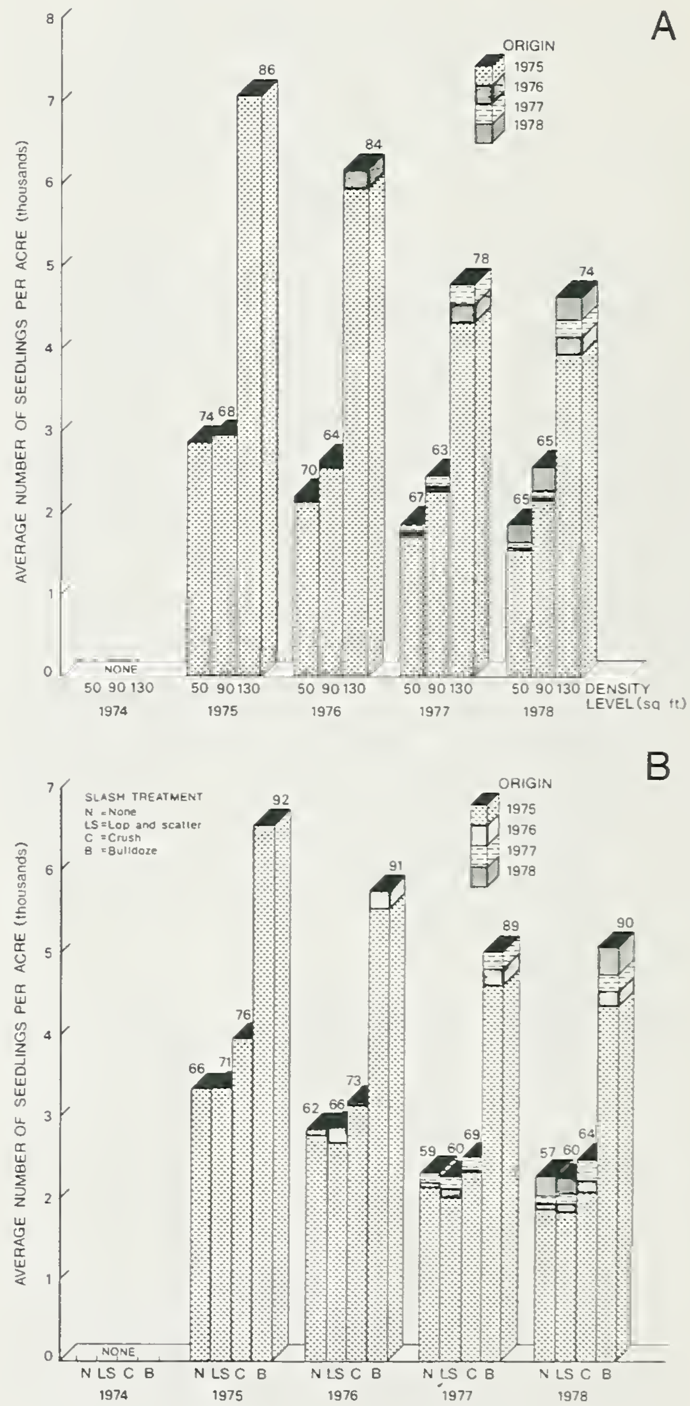

Figure 3.--Pattern of annual seedling survival (all species) from 1974 through 1978 by (A) overstory density, and (B) slash treatment. Numbers at top of bars are stocking percentages of 1-milacre quadrats.

[4] Quadrats were considered stocked if they contained at least one seedling.

The typical pattern of seedling invasion and mortality is illustrated in figure 3. About 30 to 40 percent of the large numbers of seedlings present in 1975 had died by 1978 with most of the mortality occuring during 1976 and 1977. Mortality rates of grand fir and red fir were similar. New seedlings were found on the plots each year from the light cone crops of 1975 through 1977 but not in sufficient numbers to offset the losses of seedlings originating in 1975. It is apparent from these results that a year of heavy cone production soon after the seed cut offers the best chance of quickly obtaining adequate natural regeneration. Although the bulk of natural regeneration generally becomes established in "waves" following heavy seed years, it is possible to obtain satisfactory stocking from light cone crops over a number of years as long as the seed bed remains receptive. Williamson (1973) also reported that adequate natural regeneration of Douglas-fir in the Cascades of western Oregon was obtained from seedling establishment during years of low seedfall. These observations suggest that it is not necessary to schedule seed cuts to coincide with heavy seed years.

In the fall of 1978, 5 years after the study was begun, all subplots were well stocked with seedlings ranging from an average of 1,220 per acre on 90 ft^2-none treatment to 7,240 per acre on the 130 ft^2-bulldoze treatment (fig. 4). Regardless of slash treatment, the high density overstory always resulted in the most regeneration. Similarly, the bulldozed subplots always contained the most seedlings regardless of overstory density level. The proportion of pine in the regeneration increased from about 3 percent in 1975 to about 11 percent in 1978 primarily because of considerable numbers of new ponderosa pine seedlings found in the fall of 1978.

Regional standards for defining satisfactory stocking of true fir regeneration have not yet been established. At this time, an estimate of adequate stocking can be obtained by using the stocking level curves for Douglas-fir which suggest 400 to 500 trees per acre as sufficient.[5] With this standard, all subplots in this study were adequately stocked after 5 years.

The sound seed-to-seedling ratio gives an indication of the environmental conditions that affect germination and early seedling survival, lower ratios indicating more favorable conditions. The superiority of the bulldozing slash treatment for obtaining natural regeneraton is shown in these ratios for the 1974 seed year

[5] Forest Service, Region 6, Silvicultural Examination and Prescription Handbook, 2409.26d.

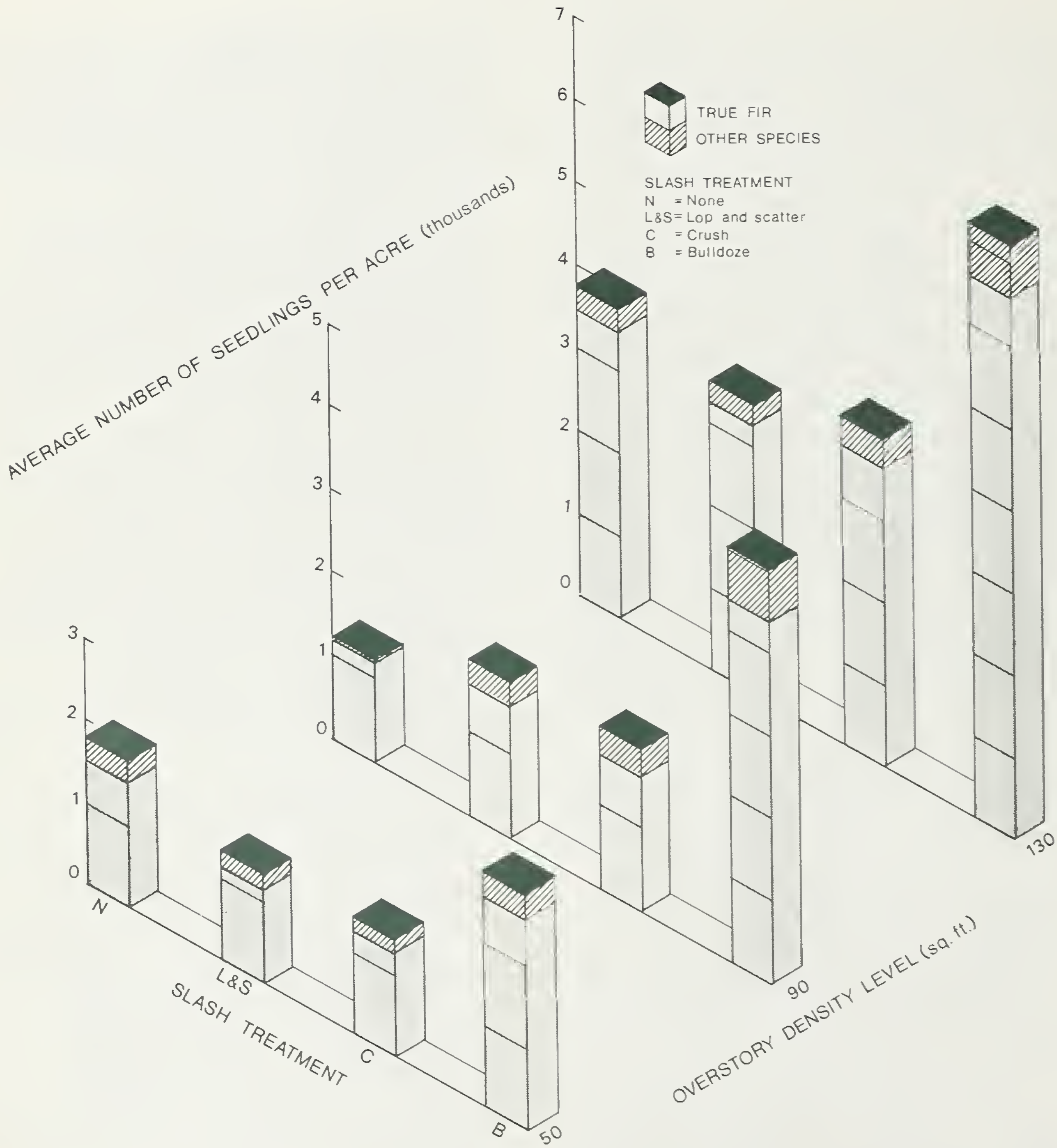

Figure 4.--Average number of seedlings per acre (all ages) established in 1978 after the fifth growing season, by overstory density, slash treatment, and species group.

(table 2). For both grand fir and red fir, the sound seed-to-seedling ratio was always the lowest for the bulldozed treatment at all density levels. Also, in all subplots, red fir was more efficient than grand fir in producing seedlings from seed having ratios some 3 to 8 times lower than grand fir. In the bulldozed subplots at the high density level, the red fir seed-to-seedling ratio was only 2:1--that is, for every two sound seeds falling in 1974, one seedling was counted in the fall of 1975.

Height growth of the fir seedlings was slow--the tallest seedlings averaging about 10 to 11 cm after 5 years (table 3). Both grand fir and red fir seedlings grew at about the same rate, and no significant differences in height existed among density levels or slash treatments. Although growth during this initial 5-year period, on the average, has been slow, many of the more vigorous seedlings showed good growth during 1978, and the rate of height growth should increase in the future (fig. 5).

Seed Bed Conditions and Regeneration

Because of the removal of nearly all organic matter on the bulldozed subplots, the percentage of milacres classified as mineral soil in 1974 was high (table 4). Litter fall during the following 5 years decreased the area of bare mineral soil and increased the number of milacres in the light litter and slash category on these subplots (fig. 6). Only minor changes in seed bed conditions occurred in the none, crush, and lop and scatter treatments since these subplots had considerable amounts of litter and slash present in 1974.

Table 2--Sound seed per seedling ratios by density level, slash treatment, and species based on 1974 seed year and 1975 seedling count

Species	Overstory density											
	50 ft^2/acre				90 ft^2/acre				130 ft^2/acre			
	Slash Treatment											
	None	Lop and scatter	Bulldoze	Crush	None	Lop and scatter	Bulldoze	Crush	None	Lop and scatter	Bulldoze	Crush
	Sound seed per seedling ratio											
Grand fir	38:1	49:1	21:1	37:1	63:1	55:1	22:1	63:1	43:1	43:1	31:1	34:1
Red fir	6:1	6:1	3:1	4:1	16:1	11.1	4:1	9:1	7:1	8:1	2:1	10.1

Table 3--Average total height of tallest seedlings per milacre, with standard errors, by species, date, overstory density, and slash treatment

Year and species	Overstory density level											
	50 ft^2/acre				90 ft^2/acre				130 ft^2/acre			
	Slash treatment											
	None	Lop and scatter	Bulldoze	Crush	None	Lop and scatter	Bulldoze	Crush	None	Lop and scatter	Bulldoze	Crush
	Centimeters											
1975												
Grand fir	2.7± .2	2.1± .1	2.2±.1	2.4± .1	2.9± .2	3.0± .2	3.0±.1	3.0± .2	2.4± .1	2.6± .1	2.7±.1	2.4± .1
Shasta red fir	2.3± .2	2.0± .2	2.0±--	2.9± .6	2.6± .2	2.0± --	3.0±.5	2.5± .2	2.3± .3	2.3± .3	2.5±.1	2.4± .2
1976												
Grand fir	5.5± .3	5.4± .6	4.6±.2	5.9± .4	6.3± .5	5.7± .4	5.7±.3	5.5± .4	5.4± .3	5.6± .3	6.5±.3	5.9± .3
Shasta red fir	6.3± .6	5.2± .4	4.3±.6	5.7± .6	5.0± .5	5.0± --	5.2±.4	4.8± .5	5.5± .5	4.3± .5	6.0±.3	5.7± .3
1977												
Grand fir	8.1± .6	8.2± .9	7.4±.4	9.2± .7	8.1± .7	8.5± .7	8.6±.5	7.3± .6	8.6± .6	8.6± .7	9.5±.5	7.9± .5
Shasta red fir	8.8± .6	7.2± .8	7.0±.5	9.5±1.1	8.7±1.0	9.0±1.2	8.5±.6	6.0± .3	7.9± .9	8.2±1.2	9.5±.7	10.5±1.3
1978												
Grand fir	11.0±1.1	11.3±1.4	10.1±.6	11.6±1.0	8.9±1.0	9.9±1.0	11.4±.9	8.6±1.2	9.7± .8	10.5± .9	12.2±.8	10.3± .8
Shasta red fir	9.9± .9	7.5± .9	10.2±.7	11.7±1.8	9.3± .9	10.0±1.8	10.2±.8	7.9±1.1	10.0±1.2	8.5±1.3	11.9±.9	10.4±1.6

Table 4--Percentage of milacres classified as mineral soil or having light, medium, or heavy amounts of litter and slash by density level, slash treatment, and year

Overstory density slash treatment, and year examined		Mineral soil	Litter[1]			Slash[2]		
			Light	Medium	Heavy	Light	Medium	Heavy
		---Percent of milacres---						
50 ft²/acre								
None	1974	4	52	18	12	50	36	10
	1978	4	52	20	16	44	40	10
Lop and	1974	6	48	20	8	76	14	6
scatter	1978	4	50	20	8	72	14	6
Bulldoze	1974	96	0	0	0	4	0	0
	1978	76	12	0	0	22	0	2
Crush	1974	14	34	14	2	62	24	0
	1978	8	32	16	4	64	28	0
90 ft²/acre								
None	1974	2	34	22	18	54	18	26
	1978	2	38	26	20	54	22	22
Lop and	1974	2	42	14	28	46	40	10
scatter	1978	2	42	14	32	42	46	10
Bulldoze	1974	92	4	0	0	8	0	0
	1978	80	10	0	0	22	0	0
Crush	1974	12	52	10	4	62	18	4
	1978	4	66	6	8	70	20	4
130 ft²/acre								
None	1974	16	28	24	2	60	20	4
	1978	6	34	22	14	62	28	4
Lop and	1974	18	36	18	8	54	18	10
scatter	1978	8	40	24	12	64	20	8
Bulldoze	1974	62	6	0	0	38	0	0
	1978	44	32	0	0	46	0	2
Crush	1974	16	56	18	0	52	16	8
	1978	12	56	20	0	66	16	6

[1]Litter:
Light: Uniform distribution of needles or small twigs over entire surface but mineral soil visible, or small patches of medium litter with mineral soil visible between patches.
Medium: Uniform distribution of needles or small twigs to about 1/4-inch depth, or small patches of heavy litter with mineral soil visible between patches.
Heavy: Needles and small twigs usually 1/4 to 3/4 inch deep but also deeper, generally in a compact mat, little or no mineral soil visible.

[2]Slash:
Light: Small pieces of slash covering less than 30 percent of surface.
Medium: Any size slash covering 30 to 60 percent of surface.
Heavy: Any size slash covering over 60 percent of surface.

Figure 5.--Some of the taller, more vigorous grand fir seedlings in the fall of 1978. Height of rule is 15 cm.

Figure 6.--Comparison of (A) bulldozed and (B) no slash treatments 5 years after treatment. Note absence of understory vegetation.

Seedling establishment on various seed beds was generally as expected--greatest on mineral soil and decreasing as litter and slash became deeper (table 5). Generally, greater amounts of litter inhibited seedling establishment more than did increasing amounts of slash. Although a mineral soil seed bed was the most favorable for germination and survival, true fir seedlings did become established in litter and slash seed beds. I observed many seedlings throughout the study area growing in light to medium litter layers but very few in heavy compact litter mats more than 1/2 inch thick. It is clear from these results that complete litter and slash removal is neither necessary nor desirable. All that is needed is to break up continuous thick litter layers so that patches of mineral soil are present

throughout the area. This is easily accomplished by logging disturbance and subsequent slash disposal operations.

Understory Vegetation

Understory vegetation was not a problem in regard to seedling establishment. In 1974, only small amounts of forbs were present on the plots and vegetation did not increase dramatically during the 5-year study period (table 6, fig. 6). Only a small number (2 to 8 percent) of milacres were classified as having medium or heavy vegetation. These results are similar to those reported by Gordon (1970) for clearcuts in true fir stands in northern California. Although in this study competition from understory vegetation was not a factor in regeneration establishment, vegetation response can be quite variable especially if seeds stored in the litter are stimulated by fire. No grazing was observed during the study period. This suggests that perhaps overstory shade had an inhibiting effect on growth of the understory.

Soil and Seedling Moisture Stress

Soil moisture was readily available to seedlings during the summer of 1975 on all plots ranging from 22 to 66 percent (weight basis) which corresponds to a soil matric potential of -0.01 to -0.1 bar (table 7). Even at the 3-inch depth, soil moisture never approached levels critical to seedling survival or growth. Precipitation during the 1975 growing season was about 2.5 inches on the study area which is about equal to the long-term summer average.

Peak moisture stress of grand fir seedlings was normal during the summer of 1975, never reaching values less than -14 bars. These soil and seedling moisture stress values are quite similar to those measured on grand fir seedlings in a fir-hemlock stand in 1973 (Seidel and Cooley 1974). It is possible, of course, that seed germination is reduced and seedling mortality occurs from rapid drying of the top few centimeters of soil.

These results indicate that once seedling roots reach a depth of 2 to 3 inches, drought is not a significant cause of seedling mortality when competing understory vegetation is absent. Gordon (1970) also concluded that because of rapid root growth of true fir seedlings, soil moisture was adequate for survival even during normally dry summers occurring in northern California.

Surface Temperatures

Surface temperatures reached levels considered lethal to seedlings on all plots. Even on high density plots, some of the 163° F (72.8° C) Tempils melted (table 8). On high density plots, there

Table 5--Average number of seedlings per milacre, with standard errors, found on milacres having none, light, medium, and heavy combinations of litter and slash by density level

Litter[1]	Overstory density level											
	50 ft²				90 ft²				130 ft²			
	Slash[2]				Slash[2]				Slash[2]			
	None	Light	Medium	Heavy	None	Light	Medium	Heavy	None	Light	Medium	Heavy
	Average number of seedlings per milacre											
None	4.6±0.6	2.0±0.3	5.0±3.0	--	5.1±0.9	3.1±0.7	3.7±2.7	--	10.7±1.1	7.4±1.2	4.5±0.5	--
Light	--	2.6±0.5	1.9±0.6	2.0±0.6	3.5±1.7	2.6±0.5	2.5±0.8	5.0±2.8	12.2±9.7	6.2±1.1	6.5±2.3	3.0±--
Medium	--	1.3±0.4	1.5±0.4	1.8±0.4	--	0.9±0.4	1.4±0.5	1.5±0.8	--	4.5±1.0	3.2±0.7	2.0±1.5
Heavy	--	--	0.9±0.6	--	--	0.5±0.5	0.6±0.2	1.4±0.8	--	3.0±--	0.4±0.2	--

[1]Litter:

Light: Uniform distribution of needles or small twigs over entire surface but mineral soil visible, or small patches of medium litter with mineral soil visible between patches.
Medium: Uniform distributions of needles or small twigs to about 1/4-inch depth, or small patches of heavy litter with mineral soil visible between patches.
Heavy: Needles and small twigs usually 1/4 to 3/4 inch deep but also deeper, generaly in a compact mat, little or no mineral soil visible.

[2]Slash:

Light: Small pieces of slash covering less than 30 percent of surface.
Medium: Any size slash covering 30 to 60 percent of surface.
Heavy: Any size slash covering over 60 percent of surface.

Table 6--Percentage of milacres having light, medium, or heavy amounts of grass and sedges, forbs and shrubs by density level, slash treatment, and year

Overstory density, slash treatment, and year examined		Grass and sedge			Forbs			Shrubs		
		Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy
		Percent of milacres								
50 ft²/acre										
None	1974	4	0	0	30	0	2	2	0	2
	1978	16	6	0	22	0	0	22	0	2
Lop and	1974	2	0	0	38	0	0	0	0	0
scatter	1978	14	2	0	20	2	0	28	2	4
Bulldoze	1974	0	0	0	0	0	0	0	0	0
	1978	22	2	0	38	6	2	42	4	0
Crush	1974	2	0	0	32	2	0	0	0	0
	1978	20	0	0	34	6	0	32	6	0
90 ft²/acre										
None	1974	0	0	0	36	4	2	0	0	0
	1978	2	2	0	16	2	0	32	8	2
Lop and	1974	0	0	0	46	2	0	0	0	0
scatter	1978	10	0	0	12	0	0	34	2	0
Bulldoze	1974	0	0	0	0	0	0	0	0	0
	1978	32	0	0	6	0	0	16	0	0
Crush	1974	0	0	0	32	0	0	0	0	0
	1978	22	0	0	18	2	0	14	2	0
130 ft²/acre										
None	1974	0	0	0	8	2	0	0	0	0
	1978	10	0	0	2	0	0	10	0	0
Lop and	1974	0	0	0	22	2	0	0	0	0
scatter	1978	8	2	0	10	0	0	14	4	0
Bulldoze	1974	0	0	0	0	0	0	0	0	0
	1978	26	4	0	18	0	0	8	0	0
Crush	1974	0	0	0	14	0	0	0	0	0
	1978	12	0	0	12	0	0	8	0	0

Column group heading: Understory vegetation type[1/]

[1/]Vegetation cover classes are: light - covering 5-30 percent of milacre; medium - 30 to 60 percent; heavy - 60 percent.

Table 7--Soil moisture content (oven dry weight basis) by overstory density, depth, and date, 1975[1/]

Overstory density level and depth of soil	July 1	July 16	July 28	August 12	September 3
	Percent				
$50\ ft^2$					
3 in	38.2±0.7	35.4±1.5	25.7±3.3	28.1±10.1	30.3±9.3
6 in	37.7±6.7	38.4±0.2	33.4±2.3	38.1±0.2	29.9±3.8
12 in	44.4±1.6	46.3±1.1	45.2±4.5	47.0±0.1	47.7±4.5
18 in	51.1±4.0	58.9±0.6	59.0±5.1	57.1±0.6	51.1±7.5
$90\ ft^2$					
3 in	35.9±1.7	42.6±1.7	27.8±4.2	32.1±8.4	27.6±5.4
6 in	37.1±6.3	38.3±2.3	36.9±2.0	35.7±5.6	35.1±6.7
12 in	41.5±2.3	47.9±0.4	40.7±2.7	40.0±1.4	39.6±4.0
18 in	58.0±5.6	60.0±16.3	60.0±18.7	55.3±9.9	56.3±3.8
$130\ ft^2$					
3 in	45.8±1.8	42.1±5.4	22.9±1.7	41.1±9.1	21.7±5.4
6 in	41.3±0.4	42.3±1.2	41.2±1.3	35.1±2.3	31.8±6.4
12 in	46.8±14.7	45.5±7.4	43.2±2.2	42.4±0.9	44.7±3.6
18 in	65.6±3.0	58.9±0.4	55.6±1.1	53.4±4.3	56.5±0.2

[1/]Each value is the mean of 3 replications. Soil matric potentials corresponding to these moisture contents were in the range of -0.01 to -0.1 bars. The soil moisture content at the -15 bar "wilting point" is about 6.0 percent.

was little difference in the percentage of 163° F (72.8° C) Tempils that melted on mineral soil and litter seed beds; but as the overstory was reduced, the temperature difference between mineral soil and litter seed beds increased. It is not the temperature alone, however, but also the duration of seedling exposure that determines mortality. Therefore a mineral soil seed bed becomes increasingly important at lower stand densities because the soil surface will be exposed to full sunlight for a longer time. Although surface temperatures were in the lethal range for young seedlings, no data are available regarding the length of exposure to these tem-

Table 8--Surface temperature, by overstory density and seed bed condition[1]

Seed bed condition	Tempil melting point (°F)			
	125	138	150	163
	---------- Percent of pellets melted ----------			
	50 ft^2/acre			
Mineral soil	100	100	60	20
Litter	100	100	100	70
	90 ft^2/acre			
Mineral soil	100	100	43	13
Litter	100	100	93	87
	130 ft^2/acre			
Mineral soil	100	100	33	10
Litter	100	100	47	13

[1]Each value is the mean of 3 replications.

peratures or the reponse of true fir seedlings to various high temperature-time combinations. Therefore, although it is likely that high surface temperatures were a factor in seedling mortality, the actual importance of these lethal temperatures cannot be determined.

Overstory Mortality

Of the 210 residual overstory trees left on the plots after logging in 1973, 17 were lost during the 5-year study period--12 were blown down and 5 died--apparently from exposure shock. Overstory mortality was not related to residual stand density; four trees were lost in the low density plots, eight in the medium density, and five in the high density. In unmanaged old-growth stands such as these, trees have not developed the windfirmness needed to resist greater wind stresses resulting from partial cuts. The risk of blowdown can be reduced by leaving dominant or codominant, full-crowned trees which are the most windfirm and also the best seed producers (Gordon 1973).

CONCLUSIONS

The use of the shelterwood system in this mixed conifer stand was successful in obtaining natural regeneration at each of the three overstory density levels. Most seedlings were established on subplots where mineral soil was completely exposed, but regeneration was also adequate on seed beds where compact litter mats were broken up and litter and duff did not exceed 1/2 inch in depth. Complete litter and slash removal is not necessary or desirable since a suitable seed bed is provided by logging and slash disposal operations which break up heavy litter and duff layers and expose mineral soil. It appears that the species composition of the reproduction will be similar to that of the old-growth stand; about 85 percent true fir and 15 percent ponderosa, lodgepole, and white pine. The bulk of the regeneration occurred from one heavy seed crop during the 5-year period. Because of the absence of competing understory vegetation, however, the seed bed remained receptive throughout the 5-year study period, and some seedlings became established every year. Most of the seedling mortality took place during the first 2 years after the heavy seedfall and apparently was caused by high surface temperatures rather than drought.

Determination of suitable residual stand density to leave after the seed cut when using the shelterwood system depends upon the amount of natural regeneration expected and the subsequent loss of established seedlings when the residual overstory is removed. Obviously, no more trees than necessary to obtain adequate regeneration should be left after the seed cut because avoiding mortality and damage to reproduction during overstory removal and slash disposal generally becomes more difficult as overstory density increases. In this specific study area (a mixed conifer/manzanita community with a south aspect) it appears that a residual overstory basal area of about 50 ft^2 per acre is sufficient to provide adequate natural regeneration within a 5-year period. Studies are currently underway to evaluate shelterwood regeneration in several plant communities and various aspects, slopes, etc. In order to minimize windthrow losses of the residual overstory, only the best dominant and codominant, fully crowned trees should be left after the seed cut. This can be more easily accomplished by marking the leave trees rather than the cut trees because the marker's attention is then focused on the most desirable trees to leave.

Removal of the overstory and slash disposal without excessive loss or damage to the established reproduction is critical to the successful application of the shelterwood system. Barrett et al. (1976) have shown that it is possible to preserve adequate numbers

of understory ponderosa pine saplings on level topography while removing 24,000 board feet per acre. It should also be possible to remove 50 ft^2 of basal area from mixed conifer stands in gentle topography while saving enough reproduction for a manageable stand. Skillful application of logging techniques and good coordination between timber and fuel management staffs are essential to achieve this objective.

The overstory will be removed from the plots in this study in about 3 years. At that time, the effect of several logging and slash disposal methods on seedling survival will be evaluated.

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APPENDIX

Table 9--Average number of seedlings per acre (all ages), with standard errors and stocked milacre percentage by density level, slash treatment, species, and year

Year, species and milacre stocking	Overstory density level: 50 ft²/acre				90 ft²/acre				130 ft²/acre			
	None	Lop and scatter	Crush	Bulldoze	None	Lop and scatter	Crush	Bulldoze	None	Lop and scatter	Crush	Bulldoze
	Number of seedlings per acre ± standard error											
1975												
Grand fir	1,600±576	1,240±322	1,620±518	2,900±725	1,260±517	1,440±432	1,260±315	3,600± 900	4,960±1,165	4,980±1,220	6,225±1,898	6,780±1,186
Shasta fir	660±231	680±238	1,000±260	1,440±295	480±173	720±342	860±271	1,800± 333	780± 253	680± 255	575± 258	2,880± 518
Lodgepole and ponderosa pine	100± 66	--	20± 20	40± 40	20± 20	60± 50	40± 40	60± 50	80± 60	125± 94	95± 80	40± 40
White pine	20± 20	--	60± 40	40± 40	--	20± 20	20± 20	80± 60	--	45± 40	65± 55	20± 20
Total	2,380±714	1,920±422	2,700±702	4,420±884	1,760±554	2,240±706	2,180±436	5,540±1,108	5,820±1,338	5,830±1,282	6,960±1,914	9,720±1,555
Stocked milacres-percent	68	68	72	90	48	62	72	90	82	82	85	96
1976												
Grand fir	1,260±416	880±194	1,260±328	2,140±492	980±343	1,400±406	1,040±206	3,400± 816	4,440± 977	4,220± 971	5,485±1,590	6,040± 966
Shasta fir	600±230	440±155	600±156	1,120±224	400±128	660±284	560±112	1,720± 310	620± 198	600± 228	250± 95	2,440± 390
Lodgepole and ponderosa pine	100± 66	40± 30	60± 40	40± 40	20± 20	60± 40	40± 40	80± 60	100± 66	180± 60	70± 60	40± 40
White pine	20± 20	--	60± 40	40± 40	--	40± 35	20± 20	100± 66	--	45± 40	85± 65	80± 60
Total	1,980±535	1,360±272	1,980±455	3,340±534	1,400±364	2,160±648	1,660±276	5,300± 954	5,160±1,084	5,045±1,059	5,890±1,590	8,600±1,204
Stocked milacres-percent	66	58	70	88	43	58	68	88	76	82	81	98
1977												
Grand fir	1,140±342	760±160	820±164	1,820±346	760±217	1,200±300	1,020±202	3,240±745	3,280±590	3,025±666	3,790±1,023	4,800±650
Shasta fir	520±175	420±140	500±130	920±178	320± 72	520±196	620±140	1,460±200	560±179	440±168	190± 66	2,000±270
Lodgepole and ponderosa pine	100± 66	80± 60	100± 66	60± 40	20± 20	40± 35	40± 40	180± 62	140± 80	140± 80	225± 90	240± 80
White pine	20± 20	20± 20	60± 40	60± 40	--	60± 40	80± 60	160± 60	60± 40	80± 60	40± 40	80± 60
Total	1,780±445	1,280±243	1,480±278	2,860±363	1,110±229	1,820±423	1,760±293	5,040±779	4,040±687	3,685±700	4,245± 998	7,120±742
Stocked milacres-percent	66	52	64	86	38	58	70	86	72	71	72	96
1978												
Grand fir	1,040±284	780±160	900±186	1,700±287	740±212	1,100±245	1,040±206	3,060±676	2,900±500	2,880±602	3,445± 910	4,680±633
Shasta fir	480±125	380± 94	400±107	920±178	460±103	520±196	620±140	1,400±192	580±185	365±139	195± 68	1,900±255
Lodgepole and ponderosa pine	260± 80	160± 60	80± 60	280± 76	20± 20	260±114	260± 94	420± 91	220± 87	205± 70	320± 139	540±152
White pine	20± 20	20± 20	60± 50	20± 20	--	20± 20	60± 40	180± 62	60± 40	55± 45	45± 40	120± 68
Total	1,800±410	1,340±233	1,440±270	2,920±371	1,220±254	1,900±442	1,980±330	5,060±782	3,760±615	3,505±657	4,005± 942	7,240±755
Stocked milacres-percent	64	54	56	86	36	62	72	90	72	64	65	94

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1979. Natural regeneration after shelterwood cutting in a grand fir-Shasta red fir stand in central Oregon. USDA For. Serv. Res. Pap. PNW-259, 23 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Natural regeneration was good to excellent 5 years after shelterwood cutting to three overstory densities (50, 90, and 130 ft^2 per acre) in a mixed conifer stand on the Deschutes National Forest in central Oregon. Seedling density ranged from about 1,875 per acre on the low density plots to 4,627 per acre on the high density plots and consisted of about 85 percent true fir (grand and Shasta red) and 15 percent ponderosa, lodgepole, and western white pine. Mineral soil was the most favorable seed bed for germination and seedling survival, but many true fir seedlings did become established in light to medium litter layers. A residual overstory of about 50 ft^2 of basal area per acre appears adequate to provide natural regeneration within a 5-year period.

KEYWORDS: Shelterwood cutting method, regeneration (natural), grand fir, *Abies grandis*, Shasta red fir, *Abies magnifica* var. *shastensis*, Oregon (central).

GPO 989-112

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